Report on

(6) THE HISTORY OF FALLOUT PREDICTION.

by

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In November 1957, the armed forces issued a new weapons effects manual (Ref 6). The Army's version was TM 23-200. Like PVTM-18-56, the residual radiation material in TM 23-200 was not a true model, but a simplified handbook prediction system. Also as with the PVTM, it was based primarily upon the dose rate contour area coverage of actual test shots. However, since the test data available at the time the manual was being written was somewhat sparce, the current RAND model computer code was used to fill the gaps (Ref 11).

In February 1958, RAND issued another paper, RM 2115, "A New Model for Fallout Calculations" (Ref 30). A disk-tosser computer program, the model presented by RM 2115 was commonly referred to as the second RAND model. It introduced several refinements over P-882-AEC including wafers having a horizontal distribution of activity that tapered off at the edges (possibly in an attempt to reduce the need for smoothing the results) and the capability to vary some of the input parameters such as the particle size/activity distribution. Indeed, a stated purpose of the model was to investigate the effects of varying these parameters in the hope of finding a set that yielded optimum results. The model also used, for the first time, an explicitly log-normal distribution of activity with particle size - a type of function that would become the standard.

In June 1958, yet another new RAND model was described in RM 2193, "A Simplified Model for Fallout Calculations" (Ref 31). After its experiences with the disk-tosser programs, codes requiring a great deal of computer time, RAND began to search for methods to simplify the calculations of particle transport. By manipulating equations, performing empirical fits, and making some simplifying assumptions, a set of equations that could be solved by hand were sought. Such a set was arrived at, but the authors of the report decided that the solution was so difficult to obtain that whatever might have been gained relative to the unwieldy computer programs was more than offset by the loss of a clear mathematical description of the physical processes of fallout. Although even the authors admitted that the paper was somewhat of a dead end, the paper was the beginning of a transition at RAND.

One of the assumptions used in RM 2193 was a homogeneous cloud. This allowed the cloud to be transported not just as individual wafers but more as a unit to be "smeared" on the ground. It thus became useful to talk in terms of the fraction of the cloud arriving at a point on the ground, and the irregularities of the disk-tosser were replaced by smooth contours. This transition would be completed at RAND with its next report, and the concept would be adopted by at least one other group.

In January 1959, however, a model was presented that no only did not follow this trend to "smearing" the cloud, but went the other direction to introduce a new class of model that sought to describe the fallout process in greater detail. The Naval Radiological Defense Laboratory's "D" model, described by Anderson in USNRDL-TR-289 (Ref 2), abandoned the stabilized cloud (typically assumed to be present 5 to 10 minutes after the burst) and attempted to model a dynamic cloud from its formation within seconds following the burst, through its rise, to its eventual deposition on the ground. The methodology was essentially to allow cloud rise and particle fall to occur simultaneously; none of the actual particle formation processes to appear years later were present in the D model. At the time of its inception, NRDL-D, a disk-tosser, was probably the most sophisticated fallout model handbook approach, were of great interest to the military services for field use; but the true models were of most interest to the symposium. These were further subclassed depending on whether the model was a disk-tosser or one that "smeared" the cloud (i.e., one that did not divide the cloud into wafers).

In contrast to the 1957 symposium, the models presented in 1962 gave reasonably consistent results with each other and generally with the test shots. This agreement reflected a consensus among the participants that atmospheric transport of the fallout particles was becoming fairly well understood. They concluded that the emphasis in modeling research should thereafter shift to earlier times in the fallout process; e.g., cloud formation and fractionation. Of the fully working models presented, only the NRDL-D model attempted to model cloud rise. But work near completion by Miller and work recently underway by DASA on a new comprehensive model had already entered these new areas and will be noted below.

Reports on the symposium and analyses and comparisons of the models presented there took no less than six years. Although NRDL's final report on the symposium was not published until November 1965 (Ref 18), Russell (Ref 35) had written the first comparative critique of three of the important models: WSEG-10, NRDL-D, and Quick Count deriving its fallout model from RM2460.

Russell's comments on the normalization and surface roughness factors used by the models would be repeated later by others in more detail, and he did little to actually describe the merits of the three models relative to one another. But he did conclude that the particle size/activity distributions were incorrect and certainly oversimplified.

He argued that the distributions assigned too great a fraction of the activity to the larger particles and thereby overestimated local fallout doses by as much as a factor of five (Ref 35:197). His own view was that the relationship between size and activity was a very complicated one. His recommendations were to develop methods to model the thermodynamic processes in the cloud to determine the manner in which individual nuclides form in particles and to reexamine extensively the actual fallout debris collected from the weapons tests. His latter recommendation was apparently not enthusiastically acted upon; certainly it would have been a tremendous undertaking. The first recommendation was already being implemented by Miller and DASA.

Russell also made a comment that brings to the fore a major point of the fallout modeling game. This is that the best prediction methods toy with uncertainties that quite easily result in a factor of two variance in the dose for a given case. The response of the human body to radiation, however, not being in any sense linear, may amplify an error to result in a factor of 20 to 100 variance in casualties. Thus, in the cases where these models were used for strategic studies, a fine tuning of the significant digits in one of the multiplicative constants in a model was reflected in the loss or gain of many thousands of lives (Ref 35:45).

This concern over multiplicative constants (in particular normalization and surface roughness) was also evident in comments made in the aftermath of the 1962 symposium by Mackin and Mikhail in December 1965 (Ref 22), by Polan in September 1966 (Ref 26), and by Seery in November 1968 (Ref 36). Polan's work in particular shows an unexpectedly wide variation in the particle size/activity distributions used by the various 1962 models considering that the distributions typically owed their origins to the single Buster-Jangle Sugar shot. Perhaps in response to the scientists' complaints that the actual data from test shots were difficult to compile in order to analyse a fallout model, the DASA 1251 series of volumes on Local Fallout From Nuclear Test Detonations was issued in the mid-1960's (Ref 19).

The first new model to appear after the 1962 symposium, one proposed in a series of works by Carl Miller (Ref 24) and sponsored by the Office of Civil Defense, was also the first to attempt modeling the radioactive cloud thermodynamically and to attempt modeling fractionation. At the time of its appearance in 1963, it was described as the "state of the art" (Ref 22:10); but perhaps due to its difficult reading, the Miller model soon yielded the limelight to the new DASA model.

This model, a computer code named DELFIC, was intended to be very comprehensive and to be used only as a research tool rather than for operational use. Completed in 1966, the code ambitiously sought to model the entire fallout process using as much as possible first principle physics rather than empirical information. In terms of transport it was a disk-tosser; but it examined areas (such as soil composition, fractionation, individual radionuclide decay, and vertical winds) that pre-1962 codes had entirely ignored. It was in 1966, and remains today (after some modification), the last word in fallout models. But it has earned its standard-setting reputation at the expense of being rather intractable.

Because the code can be very expensive to run and extremely difficult to learn how to run, the work done since 1966 on fallout models other than DELFIC has been to develop models that approach DELFIC's capabilities without its difficulties. The models of most interest are PROFET (developed in 1969 for Army field use), SEER (appearing in at least three versions, the second appeared in 1972 as SEER II), KDFOC (1972), AUGER (a follow-on to KDFOC developed in 1975), and LASEER (a 1975 rewrite of SEER by the Los Alamos Scientific Laboratory). The models are in some cases (PROFET, SEER, and LASEER) direct derivatives of DELFIC; and in terms of particle transport, all are essentially disk-tossers. So whereas the differences between the 1962 models were most often expressed in terms of their transport methodology, the differences between the members of the current generation of models lie mainly in the compromises that are made to simplify the models relative to DELFIC.

The features that would be mentioned in a comparative analysis of the models would include map preparation, presentation of results, methods of smooting the results (from the traditional disk-tosser), cratering calculations, induced activity, subsurface burst capability, stem modeling, fractionation, turbulence, cloud rise, throwout, strongly sheared winds, vertical winds, ability to account for sail composition, height of burst adjustments, length of computations, computer core required, case of usage, amount of input data required, and (still) normalization factors. The scope of this paper precludes a comparison of these models, particularly as most of them have evolved through several variations. Norment (Ref 25) has attempted such a comparison, and his paper is highly recommended to the interested reader.

V. Histories of Specific Handbook Prediction Systems DNA EM-1, Capabilities of Nuclear Weapons

The Defense Nuclear Agency's effects manual EM-1 (Ref 10) is very widely used within the Department of Defense to evaluate nuclear weapons effects, only one of which is fallout. Its effective predecessor was TM 23-200 (Ref 38), described above in Section III.

TM 23-200 was very widely used in the late 1950's and early 1960's and played the same functional role as a manual for evaluating weapons effects as does EM-1 now. The manual was revised in 1962; but the revisions were not of major proportions, possibly because the feverish pace of weapons testing (following the end of the moratorium begun in 1958) left little manpower to write the revisions or evaluate the latest test data. In 1969, though, the Defense Atomic Support Agency (successor to AFSWP and predecessor to DNA) was instructed to completely rewrite the effects manual. The end result of this effort was the current version of DNA EM-1 (Ref 11).[2]

EM-1 has two major sections on fallout prediction: one covers bursts over dry land, and the other treats bursts over or under water. The information on water bursts is presented as an extensive set of dose rate contours for various burst conditions. These contours were generated by a computer code named DAEDALUS (Ref 10:V-107) developed by the Naval Radiological Defense Laboratory. The code is apparently no longer used (Ref 11).

The land burst fallout information is presented as idealized H+1 hour dose rate contours, where the contour parameters (dose rate, downwind distance, maximum crosswind width, downwind distance to maximum

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[2]The detailed transition from TM 23-200 to the current DNA EM-1 dated 1 July 1972 (Ref 10) is not well understood by the author. The authentication page forwarding DNA EM-1 (1972) states that it supercedes DASA EM-1 dated January 1968 (redesignated DNA EM-1 in July 1971, upon the organization of DNA). Furthermore, it is stated that whatever effects manual was in effect prior to the date, it was re[illegible]gnated DASA EM-1 on 8 July 1966. Precisely where these other ver[illegible]ons of "EM-1" originated, how they were related to TM 23-200, or what the forerunner of DASA EM-1 of July 1966 was, is unknown. However, it is known that DASA EM-1 was significantly different in its structure and content than the current DNA EM-1 (Ref 6).

width, and ground zero diameter) are presented as a function of yield in a family of graphs for various effective wind velocities. As stated in the manual (Ref 10:V-72), the contours were generated by the computer code DEFIC using a 15° effective shear. However, further inquiry into the source of these contours has yielded a more complete picture than that given in the manual.

DELFIC, generally regarded as the most reliable fallout prediction model available, was the primary, but not the sole, generator of the idealized contours presented in EM-1. The precise data concerning weather and burst conditions input to the code are, however, no longer available. Particularly, the wind velocity variation with altitude used by the authors of EM-1 to produce the ultimate effective wind with 15° shear has apparently been lost. Therefore, any attempt to confirm the origin of the contours by directly comparing them with results of a DELFIC run would be very difficult and subject to a significant degree of doubt. Moreover, according to the author of EM-I DELFIC was not the sole source of the information yielding the contours (Ref 11).

Due to the cost involved in running the large DELFIC code, extensive use was also made of the SEER code (Ref 20). Although comparisons of the results from SEER and DELFIC were made to insure consistent data for construction of the contours, the use of the SEER code introduces an additional obstacle in any attempt to reproduce the contours (Ref 11).

<u>Effects of Nuclear Weapons (1977 edition)</u>

The 1977 edition of <u>Effects of Nuclear Weapons</u> (Ref 15) is the latest link in a chain of books originating with <u>Effects of Atomic Weapons</u> published in 1950. Unclassified and published by the government, the books have been easily available and widely used.

The information in Effects of Nuclear Weapons (ENW) is directly attributable to the contour parameter graphs presented in DNA EM-1. However, the information in ENW has been reduced from the series of graphs to a short set of yield-dependent equations giving the contour parameters (downwind distance, maximum width and ground zero width for eight dose rates at H+1 hour) with scaling laws used for variations in yield and effective wind speed. Through EM-1, then, the real roots of the scheme lie in DELFIC and SEER (as explained above) (Ref 11).

Although, as pointed out earlier, it would be extremely difficult to directly compare ENW predictions to DELFIC results, direct comparison of results from ENW to those from EM-1 is a simple matter. Such a comparison has shown the two methods to agree remarkably well considering the differing approach to calculation of the contour parameters.

The Army Fallout Prediction System (FM 3-22)

The Army fallout prediction system is a scheme developed in 1957 or 1958 to serve the Army's needs in the field. Its purpose was not to truly model the fallout phenomenon, but to predict with a high degree of confidence an area within which the actual fallout pattern would appear. The object was not to predict the precise location of the actual dose rate contours, but to define a larger area within which field measurements would determine the dose rate information to be used for tactical decisions.

The system was very simple and designed to be performed entirely by hand. In essence, the prediction consisted of constructing a fan of 40 degree angular spread, the apex centered at ground zero, opening downwind, with the downwind extent of two hazard zones determined from

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